Large Spacecraft Antennas: New Geometric Configuration Design Concepts

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Several unconventional approaches to the configurational design of high-gain microwave antenna reflectors are presented. These approaches provide means for improving the performance of nonfurlable antennas and for improving both aperture efficiency and stowed volume efficiency of furlable antennas.

The first class of design approaches involves relatively minor modifications of conventional dual-reflector (Cassegrain and Gregorian feed) antenna concepts. These modifications eliminate the loss of transmitted energy resulting from the reflection of energy back into the feed from the subreflector as well as the loss due to interception of rays by the subreflector after reflection from the main reflector.

The second class of concepts involves the use of a conical main reflector and multiple reflections from this main reflector and from one or more subreflectors. These concepts offer the advantage of relative ease of fabrication, inspection, and furlability associated with a single curvature (conical) main reflector. In addition, they provide configurations with very small diameter subreflectors, resulting in low aperture area blockage and small furled antenna diameters.

Introduction

The objective of this activity is to develop the technology required to design, fabricate, and test large high-gain antennas for use on spacecraft. The initial phase of this program was devoted primarily to the evaluation of existing and new antenna concepts with respect to their potential application to antennas with diameters up to 30 m.

The results of this comparative evaluation indicated that the Cassegrain feed paraboloidal antenna configuration may be applicable for antennas greater than 4 m in diameter, although the folding or furling of the

doubly curved paraboloidal reflector does present problems. It was also pointed out that significant RF losses are associated with the tendency to reflect energy back into the feed horn from the subreflector in conventional Cassegrain feed designs. Although this reflection back into the feed can be avoided by modifying the subreflector surface near the antenna axis, losses are still significant, particularly in the case of dual-frequency operation. A simple configuration design modification for Cassegrain feed paraboloidal antennas, which eliminates these losses even for dual-frequency operation, is described in the following section.

The most promising concept evolved during the initial evaluation study is the conical Gregorian antenna conceived by Ludwig (Reference 1). The use of a conical main reflector offers several potential advantages in the areas of mechanical and structural design, fabrication, surface measurement, and furling. In addition, this concept exhibits excellent RF performance characteristics.

The principal disadvantage of the conical Gregorian antenna is the relatively large diameter of the subreflector (0.4 to 0.5 times the outer diameter of the main reflector). Unless the subreflector itself is furlable, it appears that this concept is limited in spacecraft application to antenna diameters below about 10 m.

Several new antenna geometrical configurations, all using conical main reflectors, are presented. These concepts retain many of the advantages of the conical Gregorian antenna concept associated with a conical main reflector. In addition, they provide a means for greatly reducing subreflector diameters (e.g., to less than one-tenth the main reflector outer diameter).

Modified Cassegrain Feed Paraboloidal Antenna

A simple approach to prevent the reflection of energy back into the feed horn of a Cassegrain feed paraboloidal antenna and at the same time to efficiently utilize all the feed-horn energy is illustrated in Figure 1.

In this modified Cassegrain feed paraboloidal antenna concept, a ray emanating from the feed F and essentially on the antenna axis is reflected by the subreflector at point C and by the main reflector at point D. This ray then grazes the subreflector at point E. Thus, all energy emitted by the feed is reflected usefully from the antenna (to the extent that the RF waves behave like optical waves).

The main reflector surface geometry is generated by rotation about the antenna axis (through F and C) of an arc D–G of a parabola. The axis of this parabola is displaced from, but is parallel to, the antenna axis. The vertex of the parabola is at A, and its focus is at B. The subreflector surface geometry is generated by rotation about the antenna axis of an

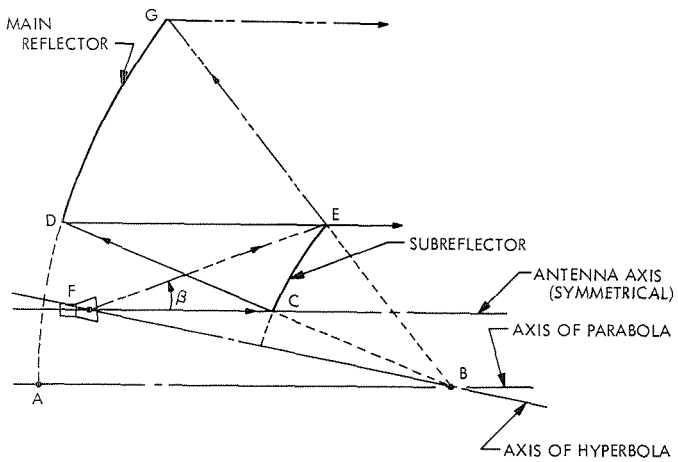

Figure 1. Modified Cassegrain feed paraboloidal antenna

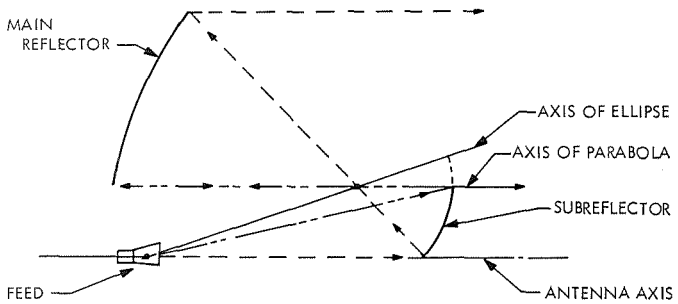

Figure 2. Modified Cassegrain with ellipse-generated subreflector

arc C–E of a hyperbola, the major axis of which passes through F and B. The subreflector thus produces an image of the point source feed F at the focus B of the parabola. The main reflector then "sees" an apparent ring source on the circle produced by rotating this focal point B about the antenna axis.

Note that this modification involves no additional elements and no increase in complexity over a conventional Cassegrain feed paraboloidal antenna design. This concept does, however, provide efficient use of the feed energy, even for dual-frequency antennas.

In concept, this modification is equally applicable to both Cassegrain and Gregorian feeds using subreflectors generated by arcs of hyperbolas or ellipses as illustrated in Figures 2 through 4.

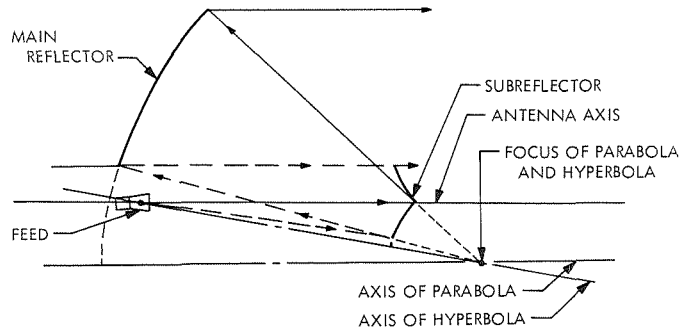

Figure 3. Modified Gregorian with hyperbola-generated subreflector

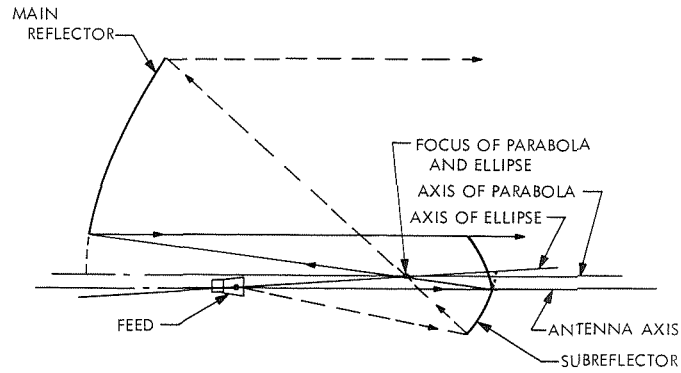

Figure 4. Modified Gregorian with ellipse-generated subreflector

Multiple-Reflection Conical Antenna

The basic principle of the multiple-reflection conical antenna concept is illustrated in Figure 5. The main reflector surface is a frustum of a cone with its apex at A and with a half cone angle θ. The subreflector surface is generated by rotation about the antenna axis (through A and F) of an arc B–C of a parabola. The vertex L and focus K of this parabola lie on the cone with half angle 2θ and with its vertex at A. The image F of this focus (as reflected in the main reflector cone) then lies on the antenna axis. The effective center of the feed is then placed at this focal point F. A ray leaving the feed center F and just grazing the subreflector at C is reflected by the main reflector at D, by the subreflector at B, and again by the main reflector near D. This ray then emerges from the antenna parallel to the antenna axis. The outermost usable ray is traced in Figure 5, traveling the path F–J–C–E and then emerging from the antenna parallel to the antenna axis. Each ray thus experiences three reflections before emerging from the antenna.

For geometrically exact and perfectly reflective surfaces, it is clear that all optical rays emanating from the feed between the cones with

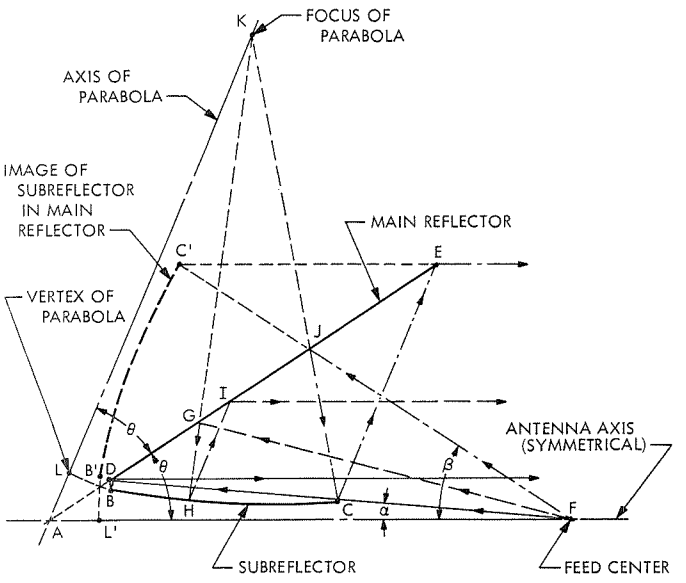

Figure 5. Multiple-reflection conical antenna

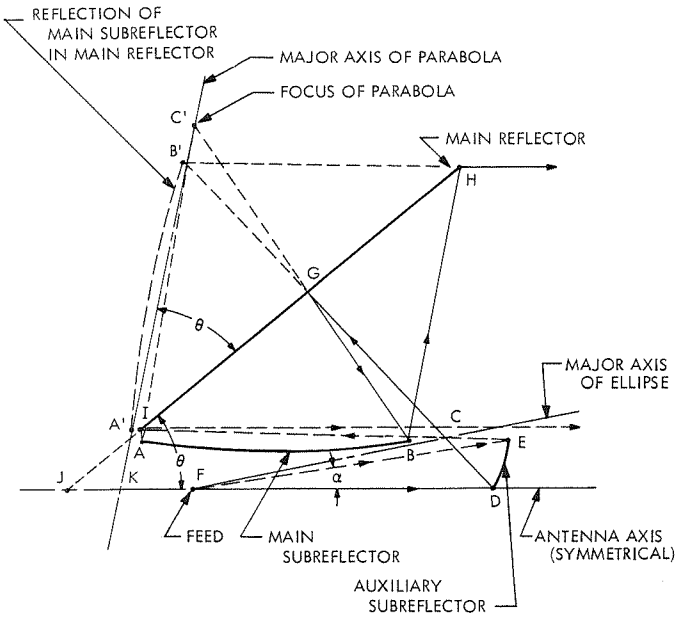

Figure 6. Multiple-reflection conical antenna with modified Cassegrain feed

half angles α and β (Figure 5) will emerge from the antenna parallel to the antenna axis. Further, it is also easily shown that all path lengths of these rays from the feed center F to any plane normal to the antenna axis and to the right of point E will be equal.

As suggested in Figure 5, the diameter of the subreflector (through point B) can be much smaller than the outer diameter of the main reflector (through point E).

It is also clear (again assuming geometrically exact and perfectly specularly reflective surfaces) that the performance of this antenna will be identical to that of a conventional focal point feed paraboloidal antenna, the generating parabola for which is shown through L′, B′, and C′ in Figure 5 and with its focus at F. Thus, this multiple-reflection conical antenna configuration represents, in a sense, an optically folded version of a conventional focal point feed paraboloidal antenna.

This similarity between this concept and a conventional focal point feed paraboloidal antenna suggests that it will exhibit some of the disadvantages of the latter. The feed horn, being relatively far forward from the vertex of the main reflector, requires long feed lines, resulting in feed line losses. Further, as suggested above, all energy associated with rays emanating from the feed within the cone with half cone angle α is lost.

Both of these disadvantages can be virtually eliminated by incorporating the modified Cassegrain feed described above. One possible version of the multiple-reflection conical antenna with a Cassegrain feed is shown in Figure 6.

In this version of the multiple-reflection conical antenna, the main subreflector surface is generated by rotation about the antenna axis of a segment A–B of a parabola, the axis of which passes through K and C′ and with its focus at C′. The reflection in the conical main reflector of this focus C′ is at C, which lies above the axis of the antenna. An auxiliary subreflector surface is generated by rotation about the antenna axis of a segment D–E of an ellipse, the major axis of which passes through the effective center F of the feed and through the point C. F and C are the foci of this generator ellipse. Thus, an effective ring source is created on the circle generated by rotating the point C about the antenna axis.

Considering the geometrical properties of ellipses, parabolas, and cones, it is clear that all (optical) rays emanating from the feed within the cone with half cone angle α will ultimately radiate from the antenna parallel to the antenna axis. All path lengths associated with these rays from the feed F to any plane normal to the antenna axis and to the right of point H (Figure 6) are equal.

For geometrically exact and perfectly specularly reflecting surfaces, the performance of this antenna would be identical to that of an antenna with a main reflector surface generated by rotation about the antenna axis of a segment A′–B′ (Figure 6) of a parabola with its focus at C, with a

point source feed at F, and using the auxiliary subreflector shown in Figure 6 as the only subreflector. Thus, this version of the multiple-reflection conical antenna represents an optically folded version of a more nearly conventional antenna configuration (i.e., that of Figure 1).

Other versions of the multiple-reflection conical antenna concept are obvious from this analogy between Figure 6 and Figure 1. For instance, conical sections can be superimposed on Figures 2, 3, and 4 to illustrate the optical folding of these configurations into multiple-reflection conical antennas.

Conclusion

The modified Cassegrain feed paraboloidal antenna concept provides a simple means for eliminating RF energy losses associated with small illumination angles in conventional Cassegrain feed antennas. The application of this concept may improve the performance characteristics of such antennas, particularly those which must operate with two RF frequencies.

The multiple-reflection conical antenna concepts described above retain many of the advantages of the conical Gregorian antenna cited by Ludwig (Reference 1). In addition, proper choices of geometric parameters (e.g., cone angle and focal length of the subreflector surface generator parabola) can provide configurations with very small diameter subreflector elements. For instance, a parametric analysis of the basic configuration shown in Figure 6 indicates that a ratio of subreflector outer diameter to main reflector outer diameter as small as 0.06 can be realized. This configuration would then produce a direct subreflector blockage of only 0.36% of the main reflector projected area (as compared with 16 to 25% blockage associated with the conical Gregorian concept).

Other important antenna design criteria may, of course, preclude the practical achievement of such low blockage ratios, particularly in smaller diameter or low radio-frequency antennas. For instance, the subreflector diameter should, in general, be many (e.g., 10 or more) wavelengths associated with the operating radio frequency. It may be necessary, also, to avoid placing a reflective surface less than several RF wavelengths from the focal ring (e.g., point C in Figure 6) of the auxiliary subreflector.

It is also recognized, of course, that the introduction of additional reflecting surfaces tends to increase performance degradation resulting from deviations of reflecting surfaces from their ideal geometries. This potential disadvantage is compensated, at least partially, by the relatively small diameters of the subreflectors. In general, the smaller the overall dimensions of a reflecting surface, the easier it is to maintain small

manufacturing tolerances and the smaller will be the thermal distortions (for a given thermal environment).

The concepts presented above have been considered only from the standpoint of basic geometric feasibility and under the assumption that the RF waves behave essentially as optical waves. Practical applications of these concepts would, of course, require more detailed comparative evaluations with respect to RF performance, ease of fabrication, structural feasibility, weight, cost, reliability, and integrability with spacecraft systems. Effort is currently being directed toward the design, fabrication, and RF testing of a small (approximately 1-m diameter) model based on the version shown in Figure 6.

Reference

1. Ludwig, A. C., and Hardy, J., "Spacecraft Antenna Research: Preliminary RF Test of Conical Gregorian Antenna," in *Supporting Research and Advanced Development*, Space Programs Summary 37-63, Vol. III, pp. 42–46. Jet Propulsion Laboratory, Pasadena, Calif., June 30, 1970.